METROLOGY AND SURVEYING AT CERN : RECENT NEWS AND FACTS

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1. INTRODUCTION

The European Organization for Nuclear Research (CERN) is an intergovernmental organization with 20 Member States. It has its seat in Geneva but straddles the Swiss-French border. Its objective is to provide for collaboration among European States in the field of high-energy particle physics research and to this end it designs, constructs and runs the necessary particle accelerators and the associated experimental areas. At present more than 5000 physicists from research institutes world-wide use the CERN installations for their experiments.

The Large Hadron Collider (LHC) is the next accelerator being constructed on the CERN site. The LHC machine will mainly accelerate and collide 7 TeV proton beams or heavy ions. It will be installed in the existing 27 km circumference tunnel, about 100 m underground, which was housing the Large Electron Positron Collider (LEP). The LHC design is based on superconducting twin-aperture magnets which operate in a superfluid helium bath at 1.9 K.

Regarding Survey and Alignment, the LHC concentrates most of the activity of the "Positioning Metrology and Surveying" group, referred as "SU group" in this paper:

- 27+2x3=33 km of new beam lines to mark out,
- 3000 new components to install and align, from new reference networks,
- 4 big experiments, of which 2 huge ones (CMS & ATLAS), to assemble and align.

In addition to the maintenance of the existing equipment, the other activities of the group are mainly dealing with CNGS (neutrinos sent to Gran Sasso, at 730 km), the CLIC development programme (reduced) and its CTF3 test facility, plus a few new experiments.

The installation of LHC is beginning, and this paper will review the status of survey and alignment at CERN in the context of this project. Recent changes or trends in techniques and concepts will be summarized.

2. MAIN CONCERNS IN RELATION WITH LHC AND CNGS PROJECTS

2.1 Refinements of the geodetic parameters of CERN reference frame

The geodetic parameterisation of the CNGS project required refining our fundamental geodetic data – i.e. CERN local system versus ITRF, and CERN local Geoid versus ETRF93 and EGG97 (best fit). In addition, CLIC accuracy requirements push to investigate the micro-undulations of the geoid in relation with micrometric hydrostatic levelling. The key points on both aspects are presented in Mark Jones' papers.

2.2 LHC design & alignment tolerances

In the dual channel LHC optics, it appears that for the first time similar accuracy requirements are expressed on both dipoles & quadrupoles – thus inducing more metrological quality control at various construction stages (cf. Dominique Missiaen's poster), and more alignment cares at installation and operation stages. Regarding the low-beta sections, stability and co-linearity problems led to design special parallel galleries in two experimental areas for linking both sides (figure 1), and to set up a monitoring of the triplets (cf. Helene Mainaud-Durand' s paper).

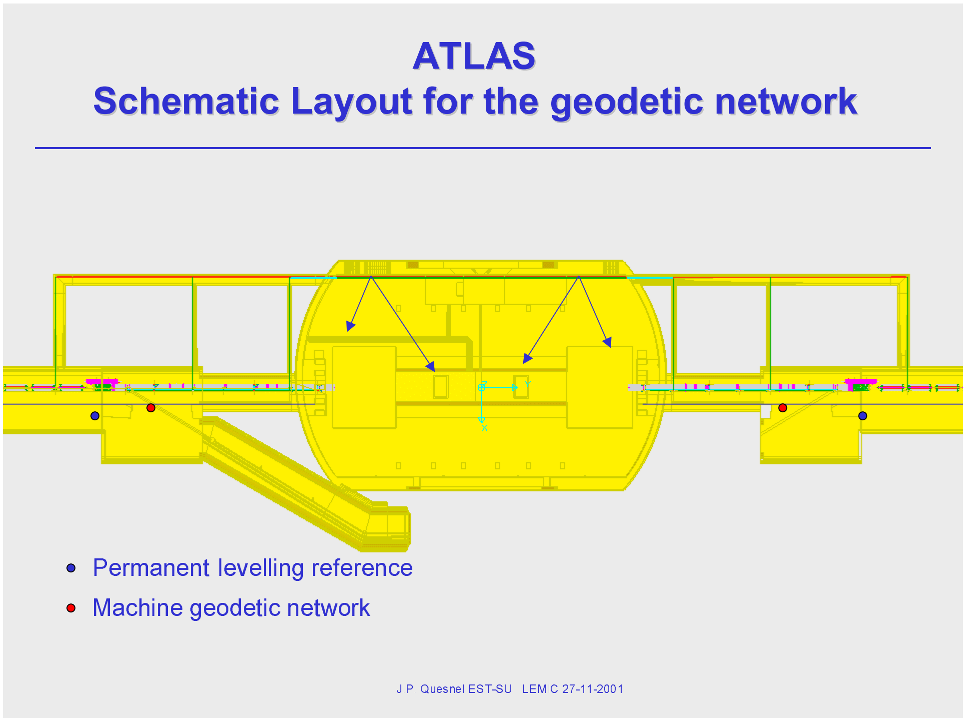

Fig. 1: Survey gallery at ATLAS experimental area

2.3 (Un)stability control and deformation analysis

From LEP experience in 10 years observation and correction of the alignment decay (through the smoothing process) for maintaining a functional alignment, a comprehensive effort had to be made for reconstituting retrospectively the integrated story of the movements of the components (cf. paper presented by Fengxiang Jin). As the search of absolute geometrical reference shapes becomes quickly a non-sense over long curvilinear traverses, the right approach leads to datum free models and local comparisons with related estimates.

From that, we concluded for the need of better follow-up and statistics from the successive re-alignments of LHC to be done according to the classical scheme :

- “ad hoc” analysis tools of movement & deformation patterns : macro-comparisons of parts (from congruency transforms) for finding large deformations and defining sectors with correlated characteristics and behaviour,
- analysis through a sliding window for locating singularities and smoothing (figure 2),
- correction of the alignment = displacements when out of the acceptance corridor,
- deduction of the local or global alignment decay factor(s) $\alpha_{(T)}$ – in other terms the dispersion growth - as a function of time (only), over homogeneous sectors as defined above, from statistics on successive epochs.

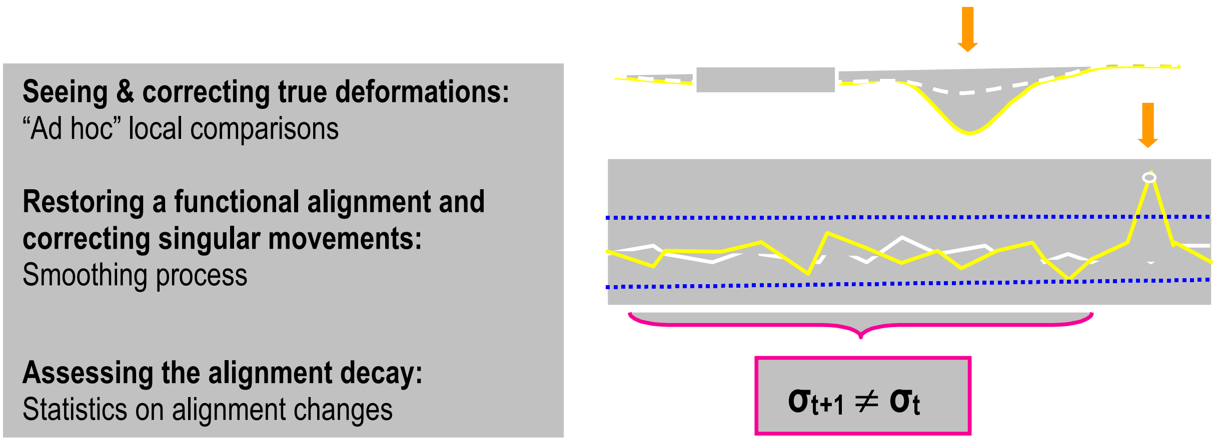

Fig. 2 : deformation analysis and smoothing

Regarding the "a posteriori" analysis of long levelling traverses over series of successive measurements, it is worth to remind here how misleading can be direct statistics of ATL type on altitudes when made without removing the "random walk" law of measurement errors - which is the only factor depending explicitly on interval L between points (cf. M. Mayoud, Ground Motion Workshop, SLAC, 6-9 Nov. 2000). The key lines of the problem are summarised in figure 3. Furthermore, even when normalising the process and using a huge amount of data (10 years of levelling around LEP), the deconvolution of the movement M(T) against the measurement noise

N(L) is not well ascertained. The alignment decay ($\alpha_{(T)} = d\sigma^2$ /time unit) is much better assessed from successive smoothing data, before correcting the alignment.

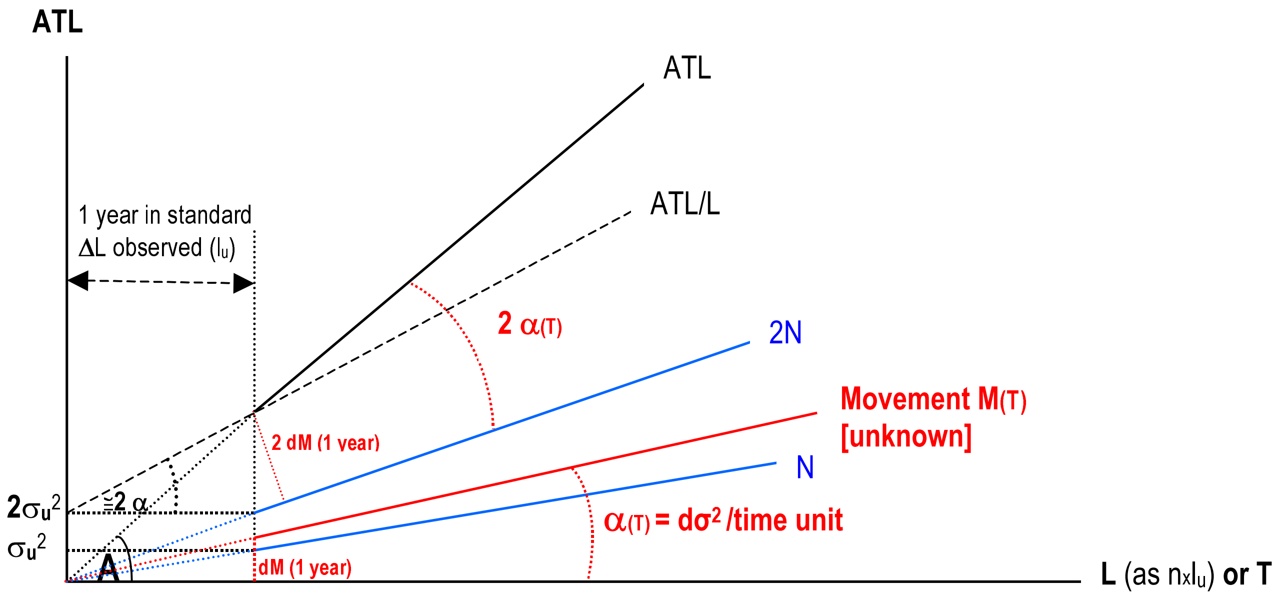

Fig. 3: Zoom around the true origin of the data

3. FAVOURITE SURVEY & ALIGNMENT INSTRUMENTS

Our choice of instruments concentrates on the following:

- Selected total stations: TDA 5500 and TC 2002 (no longer produced); Automated ones are more and more used at marking out and pre-alignment stages;
- Laser-trackers: LTD 500, used in assembly, control benches or test measurements but not for alignment in tunnels;
- Accurate length measurements: Mekometer and Distinvar, plus LTD500 ADM if needed
- Wire offset measurements: still the most efficient tool on long traverses for fast and accurate radial data in networking and smoothing.

As usual, at our level of accuracy requirements, new commercial instruments have to be carefully tested and calibrated. The subsequent interaction with manufacturers can then bring significant improvements, as illustrated in figure 4 - showing the calibration measurements with and without a distortion, strongly reduced by changes in the optics and electronics.

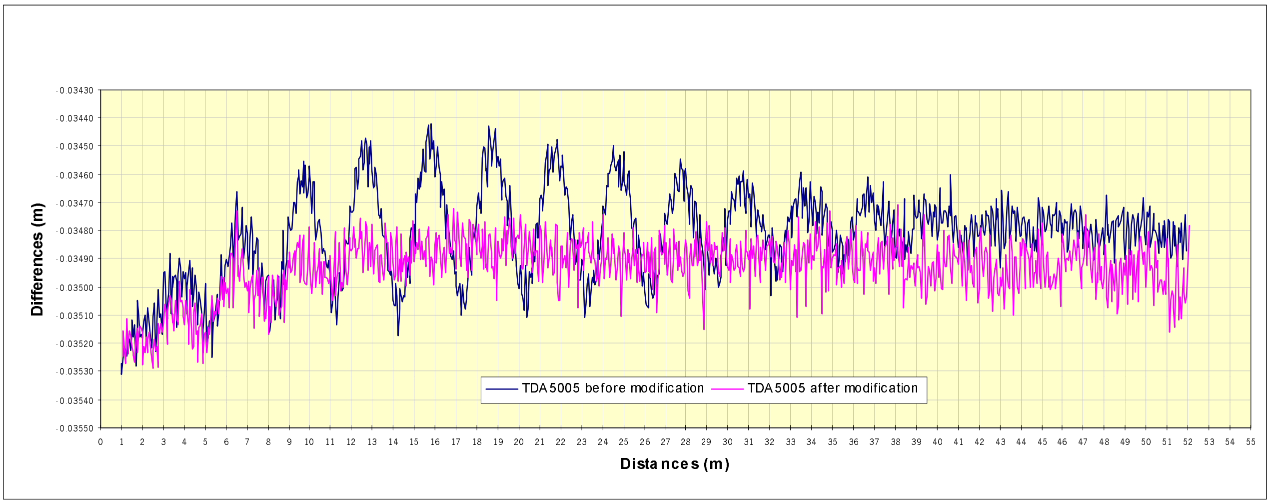

Fig. 4: Improvement of the Leica TDA 5500 from tests made at CERN

4. MAIN FACTS REGARDING METHODOLOGY

From the experience gained with the DMT Gyromat, we have tentatively introduced gyro measurements in metrological reference networks. Simulations have shown that a better contention of systematic radial errors can be expected over LHC octants or over the two new transfer tunnels - all these being nearly 3.3 km long – while keeping the smoothness with wire offset measurements. In practice, this instrument allows indeed fast measurements but its reliability remains dependent on many cares and on factors that are not all well mastered.

Digital photogrammetry was already referred as a promising method in IWAA 1999 (cf. papers from C. Humberclaude and C. Lasseur). It is now confirmed as an efficient and powerful tool, accurate enough on all dimensions to process for the metrology of all LHC detectors at construction and assembly stages : ATLAS will involve 6500 points with 16000 photos and CMS, more complex, 8500 points with 40000 photos.

With tighter requirements than LEP, the alignment of LHC low-beta sections will need both vertical and radial monitoring at micrometer level for the triplets (cf. Helene Mainaud-Durand' s paper, quoted above), and combinations of FOGALE-NANOTECH hydrostatic levelling and wire positioning systems will be used there intensively.

5. CONCLUSIONS

LHC alignment gets full benefit from new technologies in commercial instruments and from CLIC in-house development as well, without any specific problem. Nevertheless, with more sensitivity on misalignments than other CERN accelerators, with a critical threshold for movements at the interconnection of magnets and with the biggest experimental equipment ever made, the initial alignment and the maintenance surveys of the LHC complex will be a heavy task.